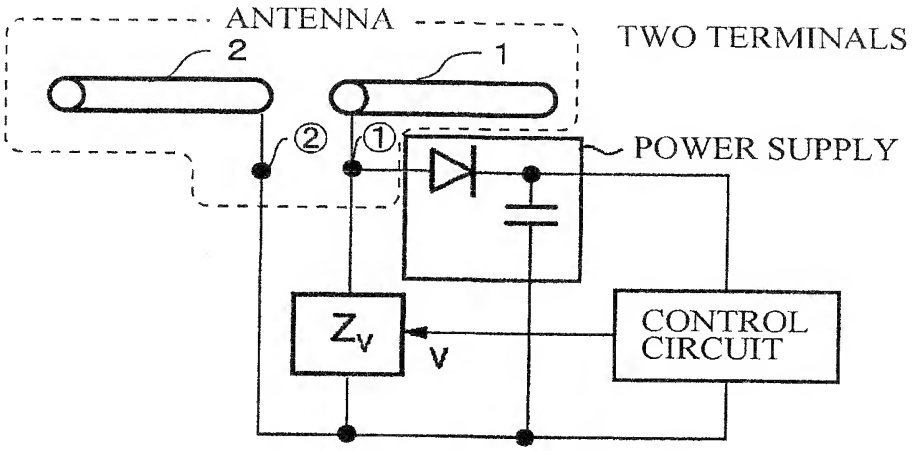
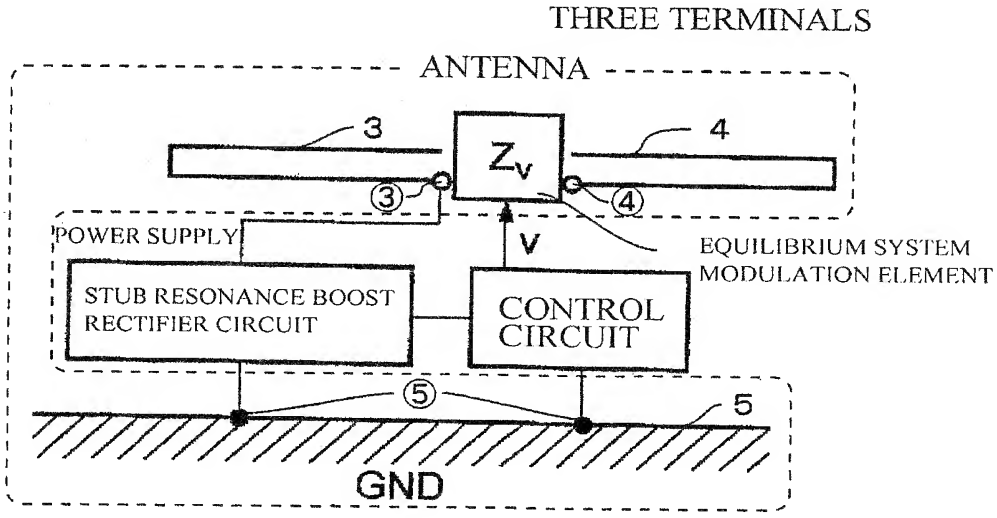
FIG.1



PRIOR ART

FIG.2



PRESENT INVENTION

FIG.3

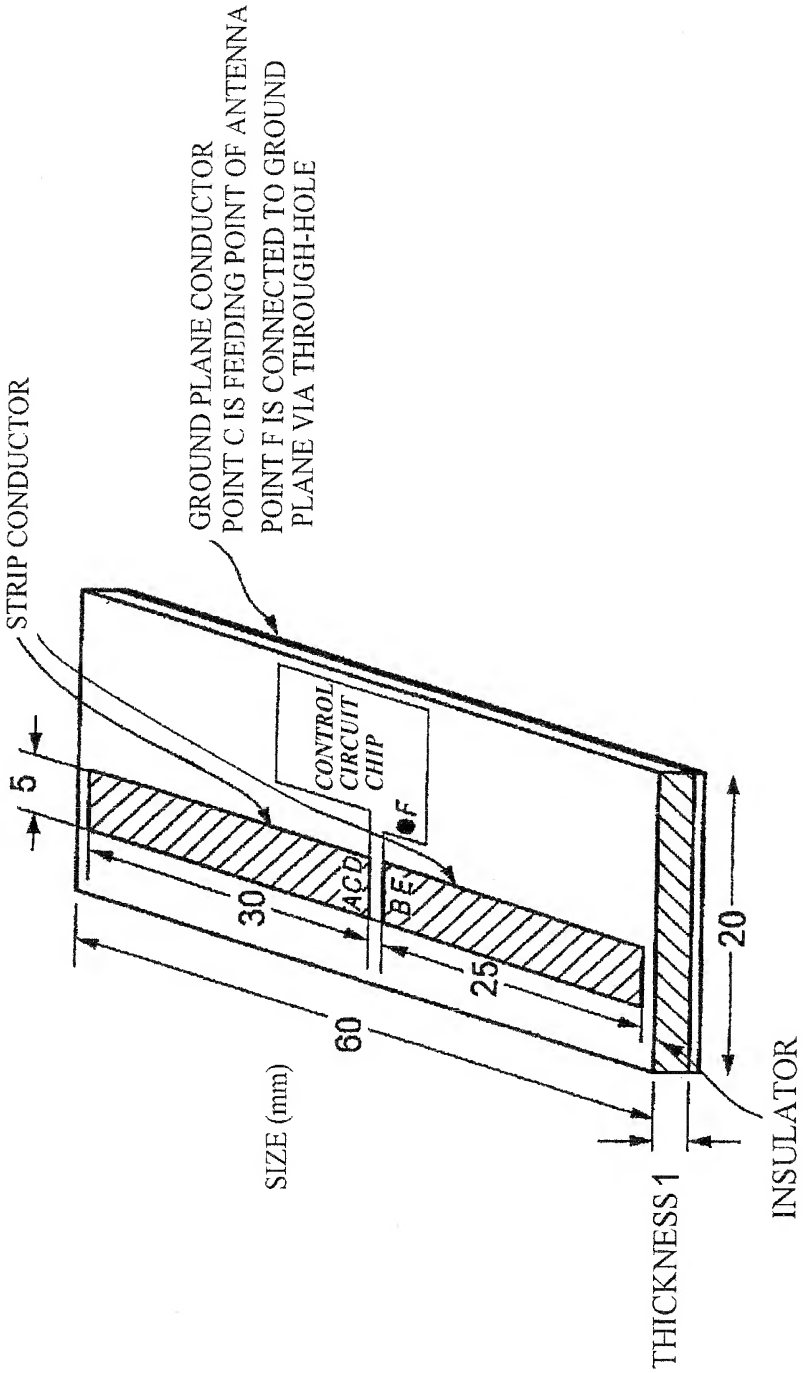

STRIP CONDUCTOR
GROUND PLANE CONDUCTOR
POINT C IS FEEDING POINT OF ANTENNA
POINT F IS CONNECTED TO GROUND
PLANE VIA THROUGH-HOLE
CONTROL CIRCUIT CHIP
F
A
C
D
B
E
5
30
25
60
20
SIZE (mm)
THICKNESS 1
INSULATOR

FIG.4

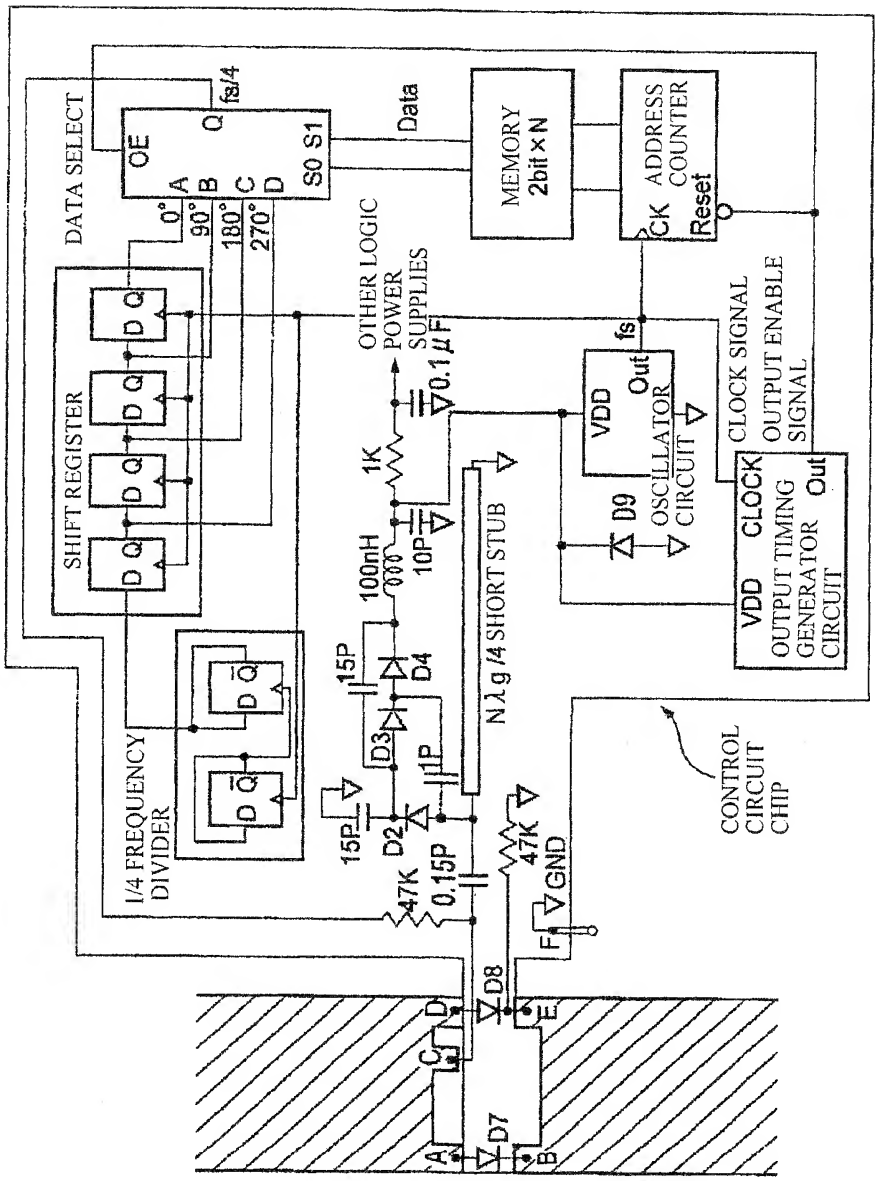

DATA SELECT
OE
fs/4
Q
A
B
C
D
S0 S1
0°
90°
180°
270°
Data
MEMORY
2bit×N
ADDRESS
COUNTER
CK
Reset
SHIFT REGISTER
D Q
OTHER LOGIC
POWER
SUPPLIES
0.1μF
1K
100nH
10P
15P
D4
D3
D2
1P
15P
47K
0.15P
47K
GND
F
D8
D7
A
B
C
D
E
N λ g /4 SHORT STUB
1/4 FREQUENCY
DIVIDER
VDD
Out
fs
OSCILLATOR
CIRCUIT
D9
CLOCK SIGNAL
OUTPUT ENABLE
SIGNAL
VDD
CLOCK
Out
OUTPUT TIMING
GENERATOR
CIRCUIT
CONTROL
CIRCUIT
CHIP

FIG.5

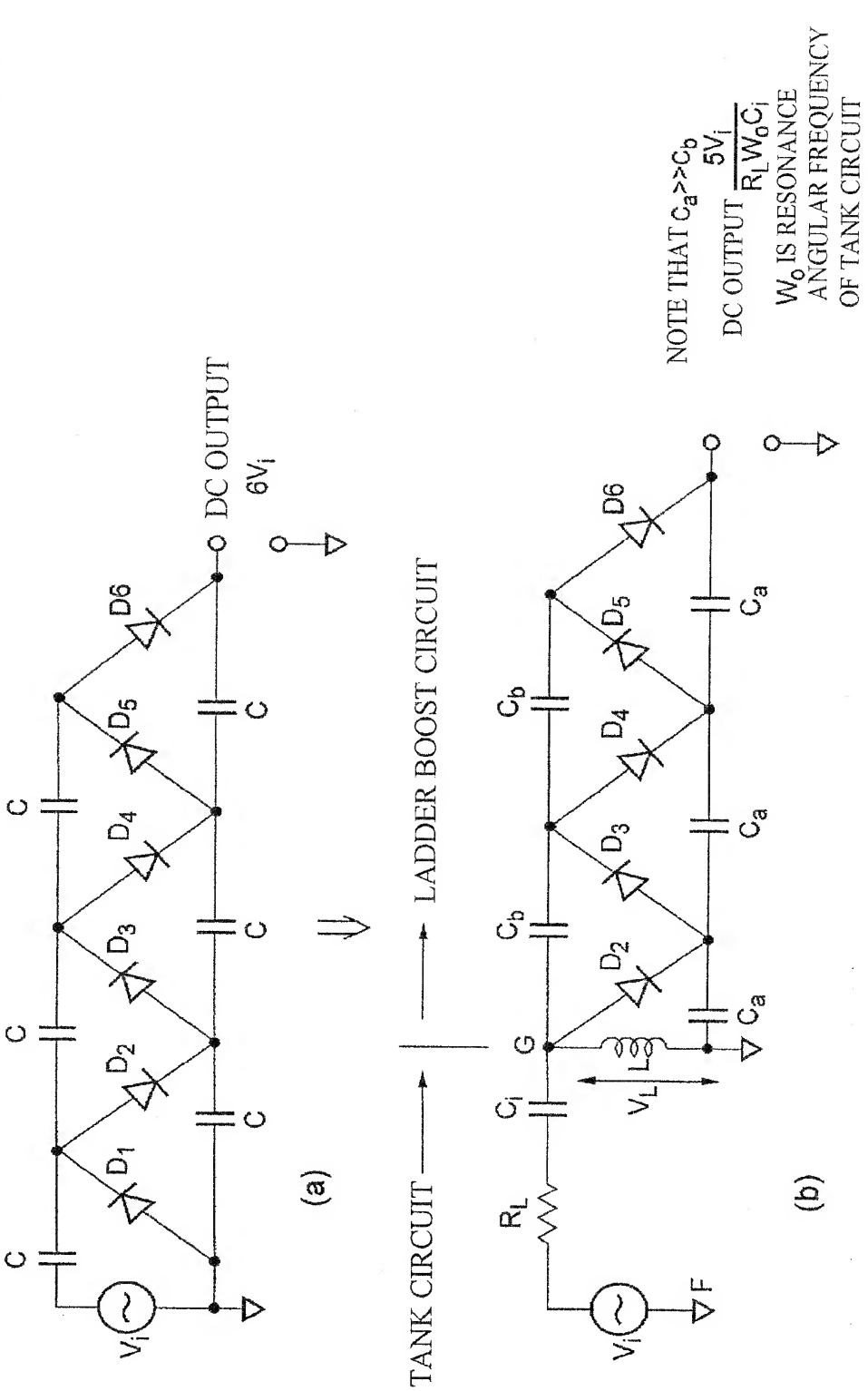
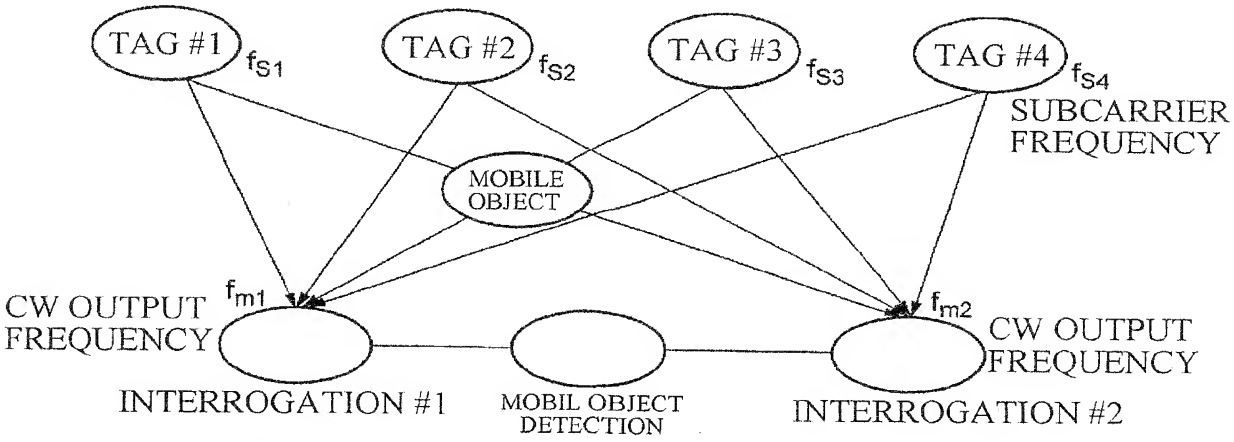

DC OUTPUT
$6V_i$
D6
D5
D4
D3
D2
D1
C
V_i
(a)
LADDER BOOST CIRCUIT
TANK CIRCUIT
C_b
C_a
C_i
R_L
G
F
L
V_L
(b)
NOTE THAT $C_a >> C_b$
DC OUTPUT $\frac{5V_i}{R_L W_o C_i}$
W_o IS RESONANCE ANGULAR FREQUENCY OF TANK CIRCUIT

FIG.6



PRESENCE OR ABSENCE OF TAG RESPONSE SIGNAL

		TAG NUMBER			
		#1	#2	#3	#4
INTERROGATION NUMBER	#1	○	○	×	○
	#2	×	○	○	○

FIG.7

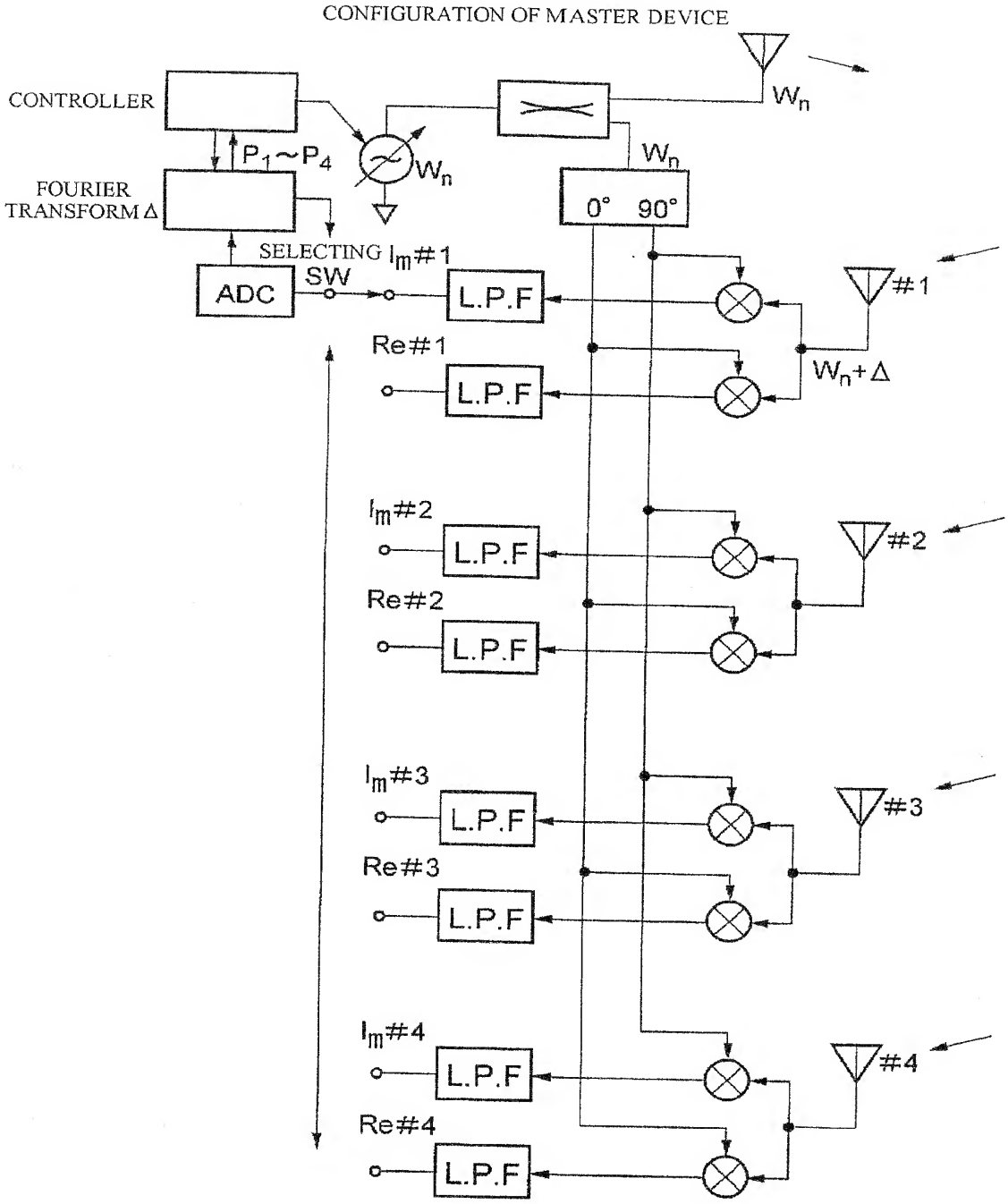

CONFIGURATION OF MASTER DEVICE
CONTROLLER
FOURIER TRANSFORM Δ
P1~P4
Wn
Wn
0° 90°
SELECTING
ADC
SW
Im#1
L.P.F
Re#1
L.P.F
#1
Wn+Δ
Im#2
L.P.F
Re#2
L.P.F
#2
Im#3
L.P.F
Re#3
L.P.F
#3
Im#4
L.P.F
Re#4
L.P.F
#4

FIG.8

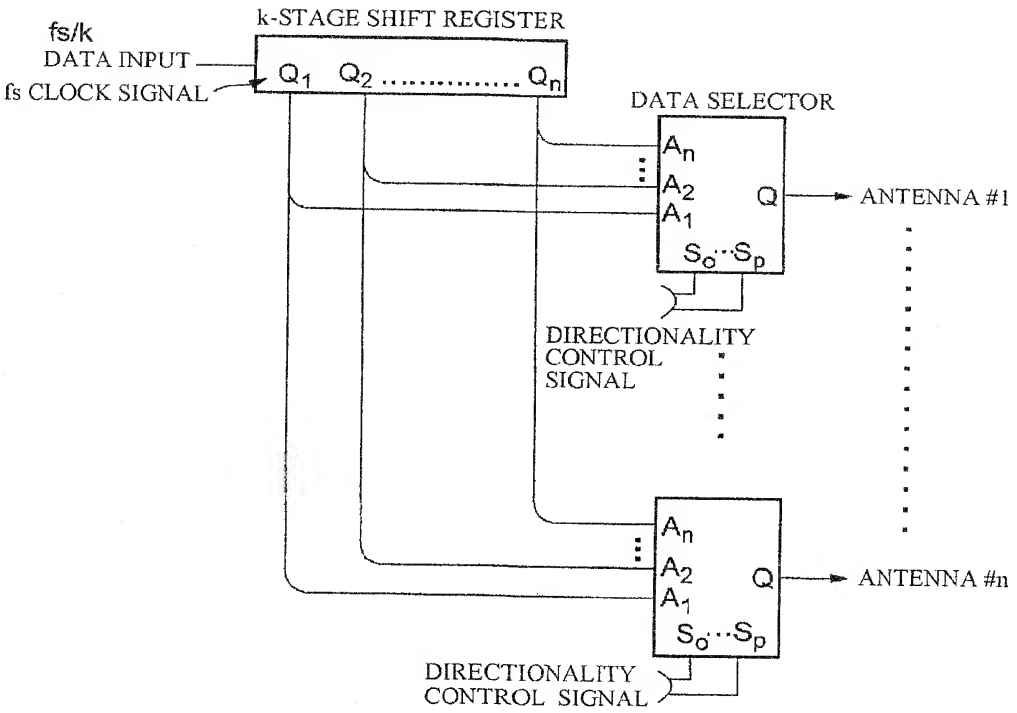

fs/k
DATA INPUT
fs CLOCK SIGNAL
k-STAGE SHIFT REGISTER
Q1 Q2 ..... Qn
DATA SELECTOR
An
A2
A1
Q
So···Sp
ANTENNA #1
DIRECTIONALITY
CONTROL
SIGNAL
ANTENNA #n
DIRECTIONALITY
CONTROL SIGNAL

FIG.9

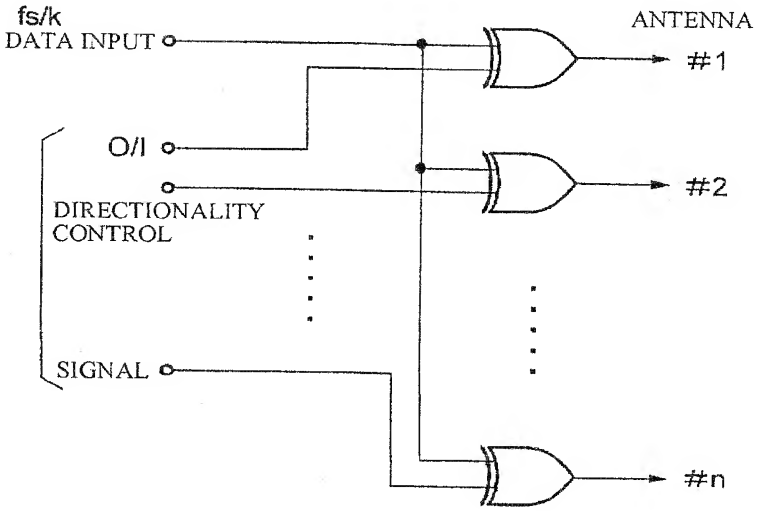

fs/k
DATA INPUT
O/I
DIRECTIONALITY
CONTROL
SIGNAL
ANTENNA
#1
#2
#n

FIG.10

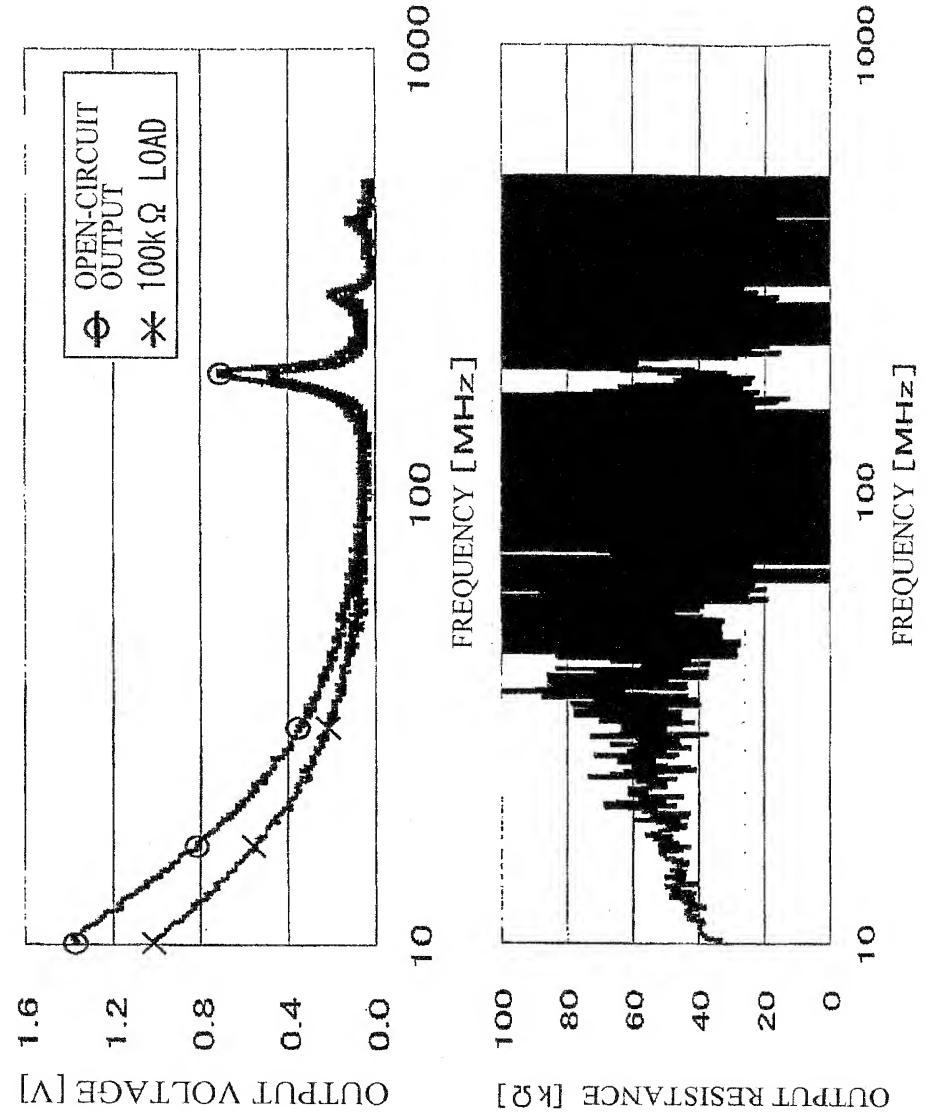

OUTPUT VOLTAGE [V]
1.6
1.2
0.8
0.4
0.0
10
100
1000
FREQUENCY [MHz]
OPEN-CIRCUIT OUTPUT
100kΩ LOAD
OUTPUT RESISTANCE [kΩ]
100
80
60
40
20
0
10
100
1000
FREQUENCY [MHz]

FIG.11

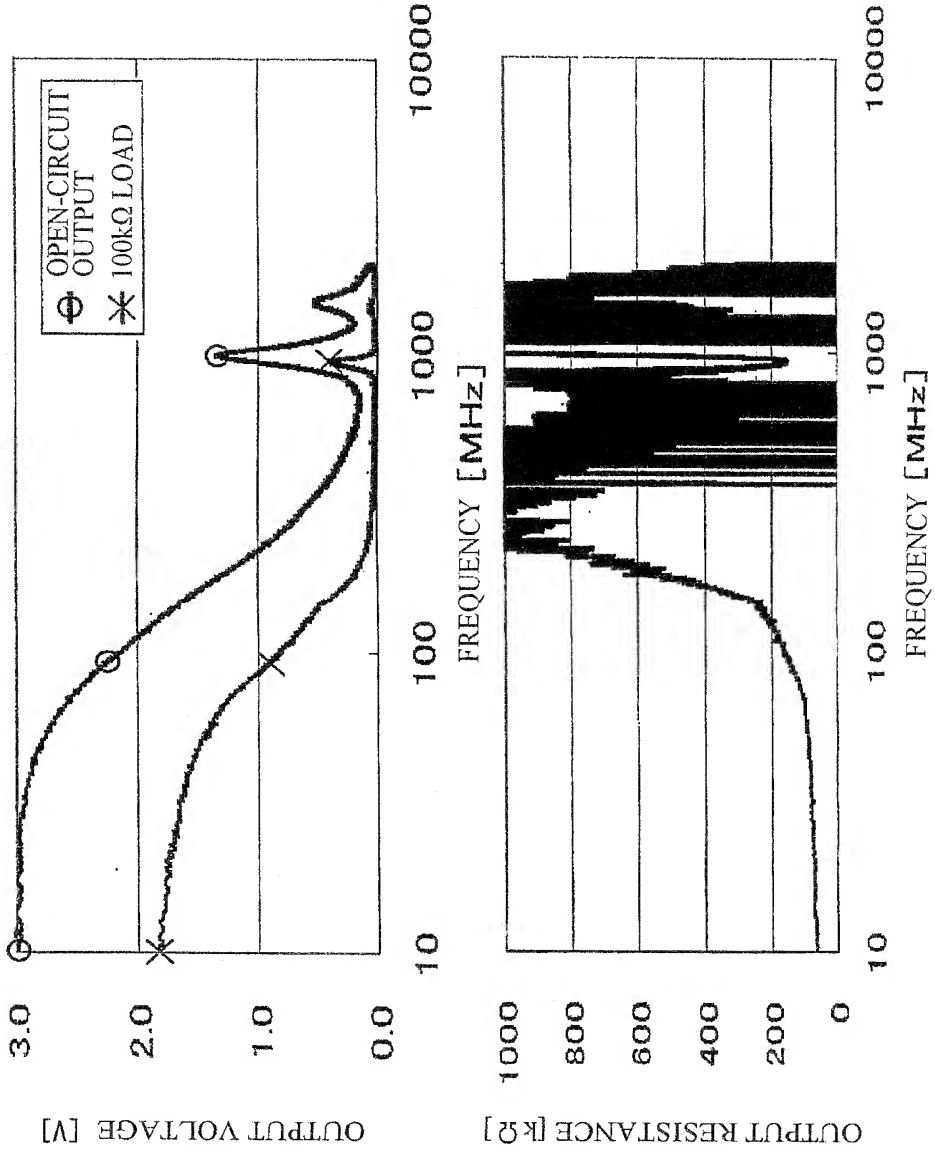

OPEN-CIRCUIT OUTPUT
100kΩ LOAD
OUTPUT VOLTAGE [V]
3.0
2.0
1.0
0.0
10
100
1000
10000
FREQUENCY [MHz]
OUTPUT RESISTANCE [kΩ]
1000
800
600
400
200
0
10
100
1000
10000
FREQUENCY [MHz]

FIG.12

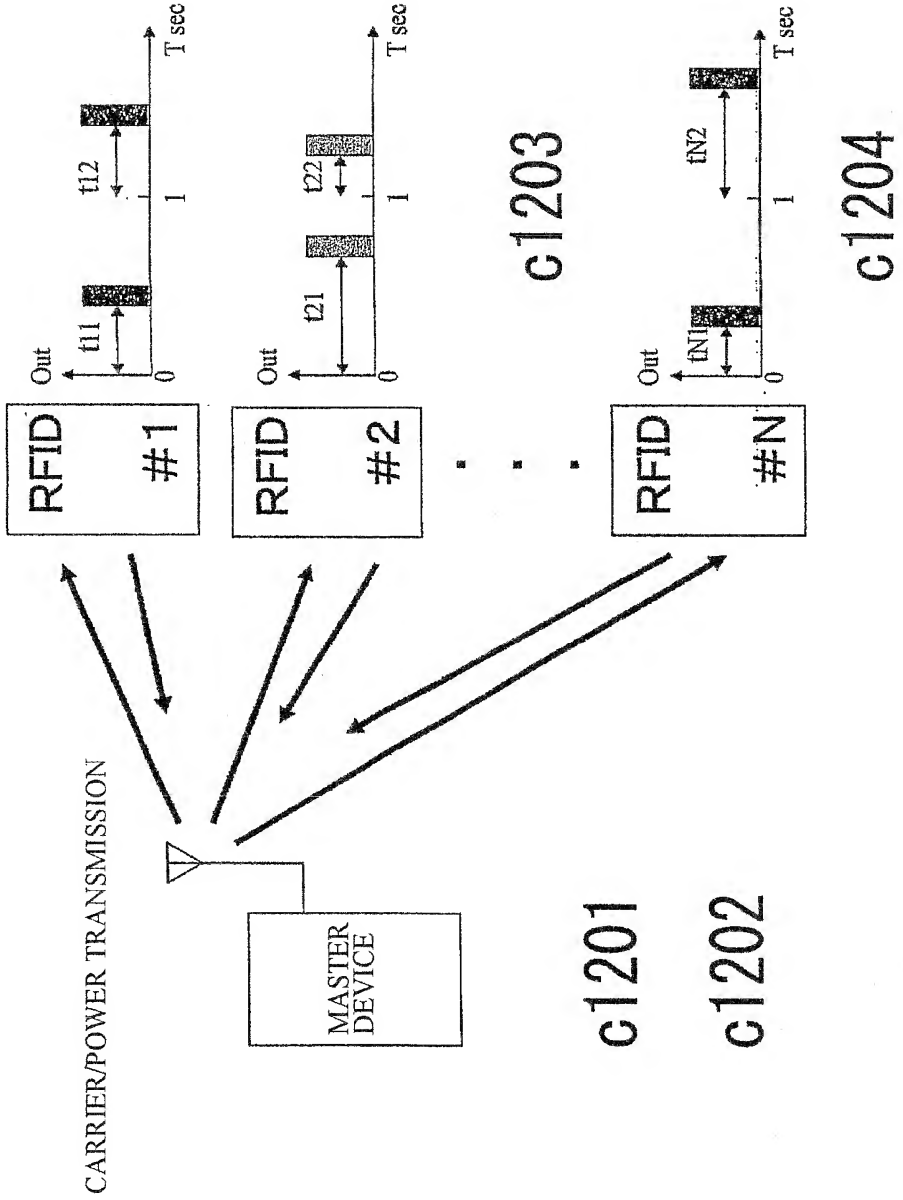

RFID #1
RFID #2
RFID #N
Out
t11
t12
t21
t22
tN1
tN2
T sec
0
1
c1203
c1204
c1201
c1202
MASTER DEVICE
CARRIER/POWER TRANSMISSION

FIG.13

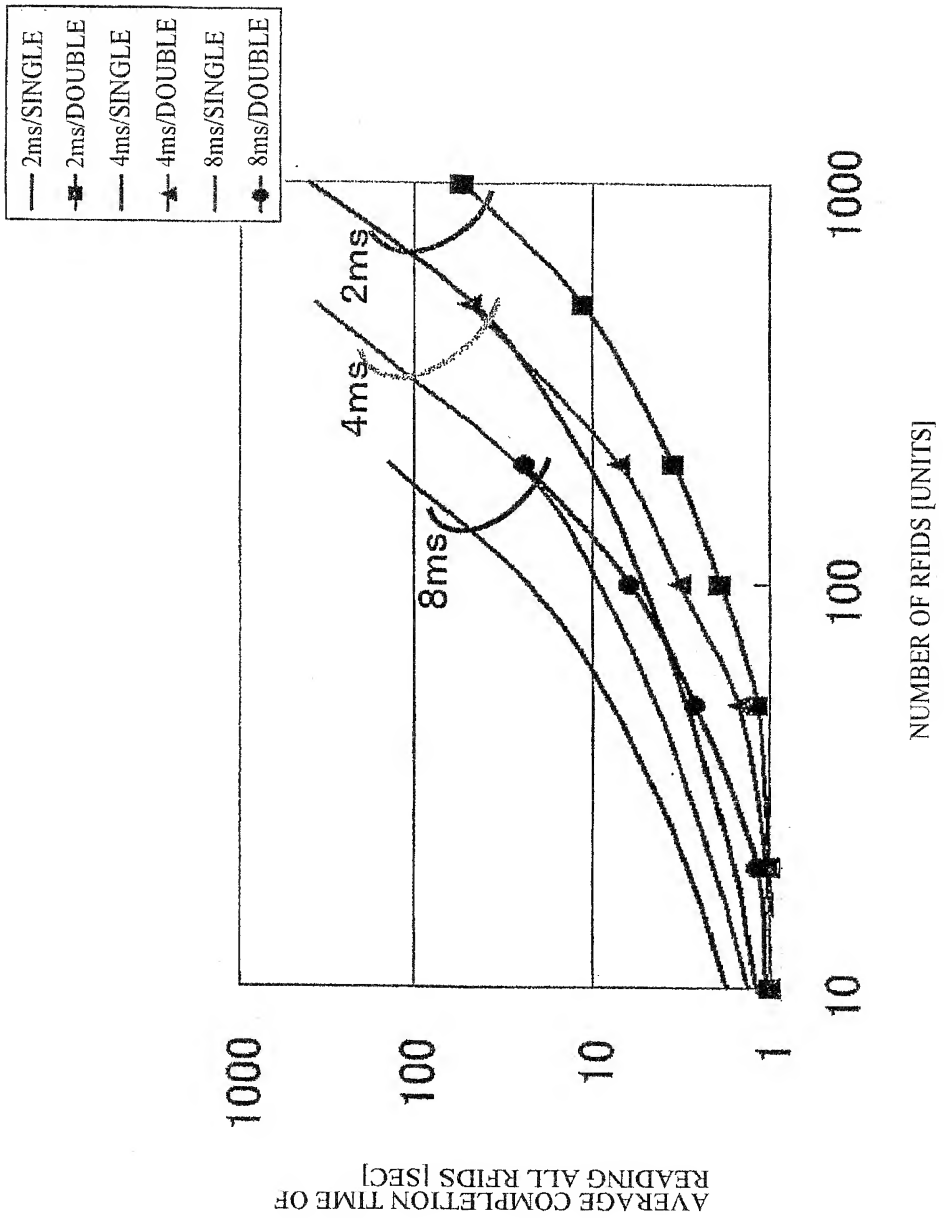

2ms/SINGLE
2ms/DOUBLE
4ms/SINGLE
4ms/DOUBLE
8ms/SINGLE
8ms/DOUBLE
2ms
4ms
8ms
1000
100
10
1
1000
100
10
AVERAGE COMPLETION TIME OF READING ALL RFIDS [SEC]
NUMBER OF RFIDS [UNITS]

FIG.14

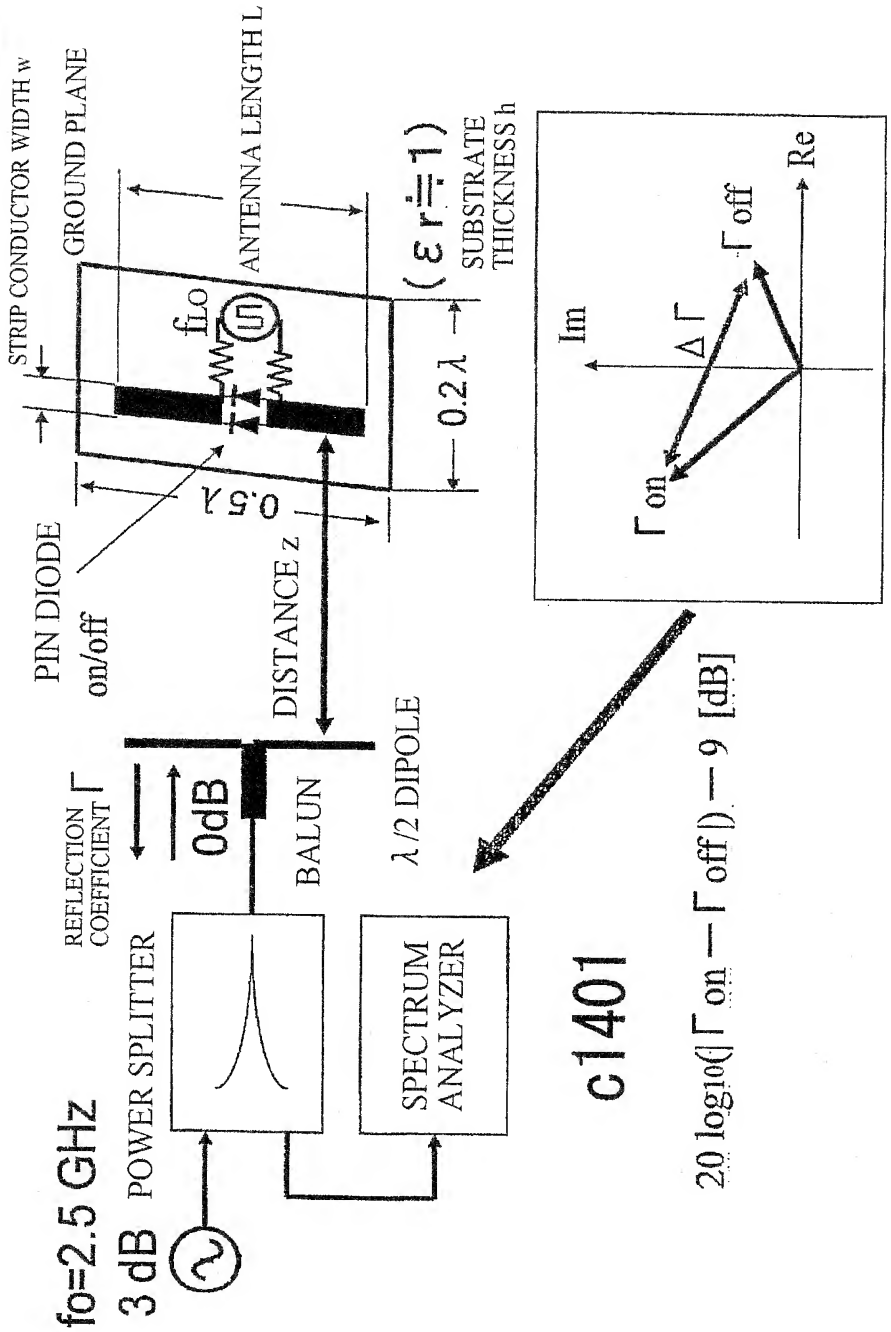

STRIP CONDUCTOR WIDTH w
GROUND PLANE
ANTENNA LENGTH L
SUBSTRATE THICKNESS h
$(\varepsilon r \doteqdot 1)$
f_{LO}
0.2λ
0.5λ
PIN DIODE
on/off
DISTANCE z
REFLECTION COEFFICIENT Γ
0dB
BALUN
λ/2 DIPOLE
fo=2.5 GHz
3 dB POWER SPLITTER
SPECTRUM ANALYZER
c1401
Im
Re
Δ Γ
Γ off
Γ on
$20\log_{10}(|\Gamma_{on} - \Gamma_{off}|) - 9$ [dB]

FIG.15

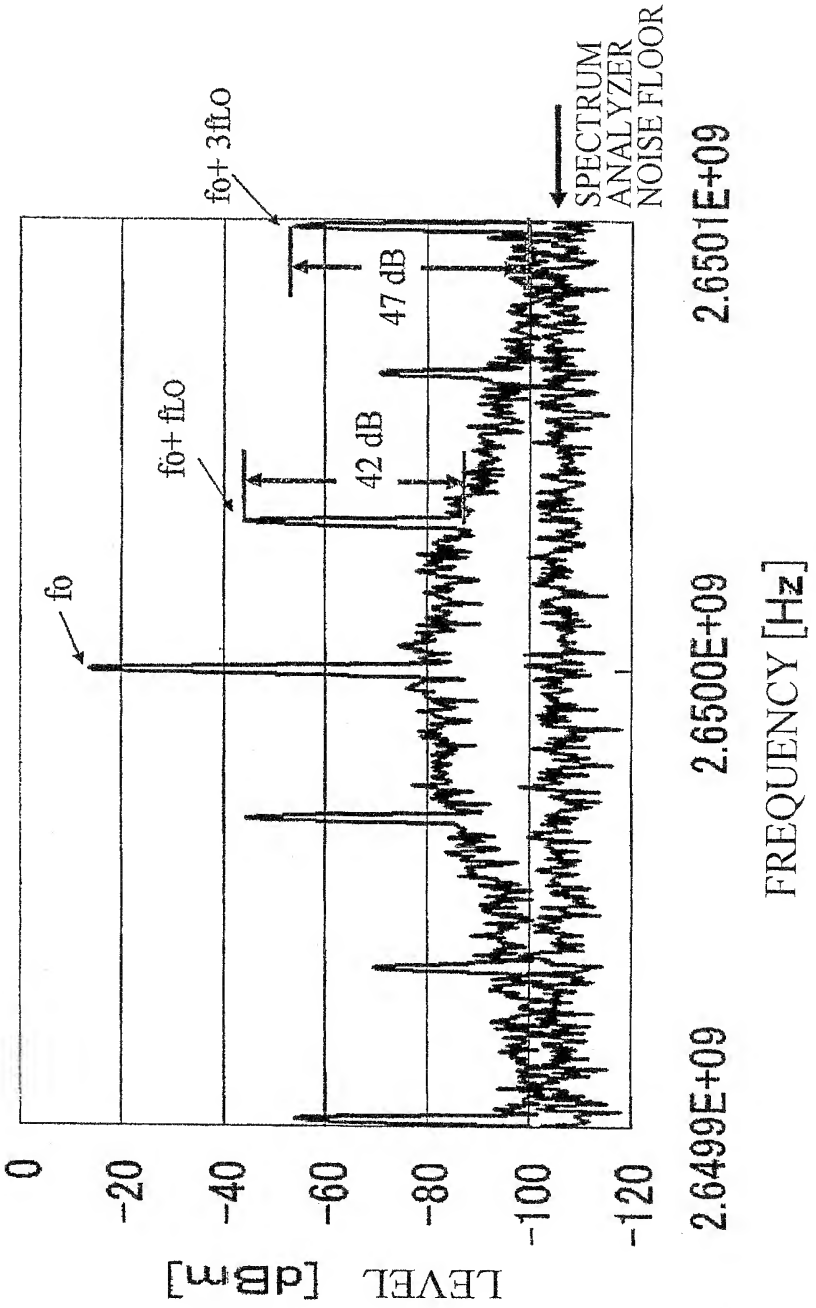

SPECTRUM ANALYZER NOISE FLOOR
fo+ 3fLO
fo+ fLO
fo
47 dB
42 dB
0
-20
-40
-60
-80
-100
-120
LEVEL [dBm]
2.6499E+09
2.6500E+09
2.6501E+09
FREQUENCY [Hz]

FIG.16

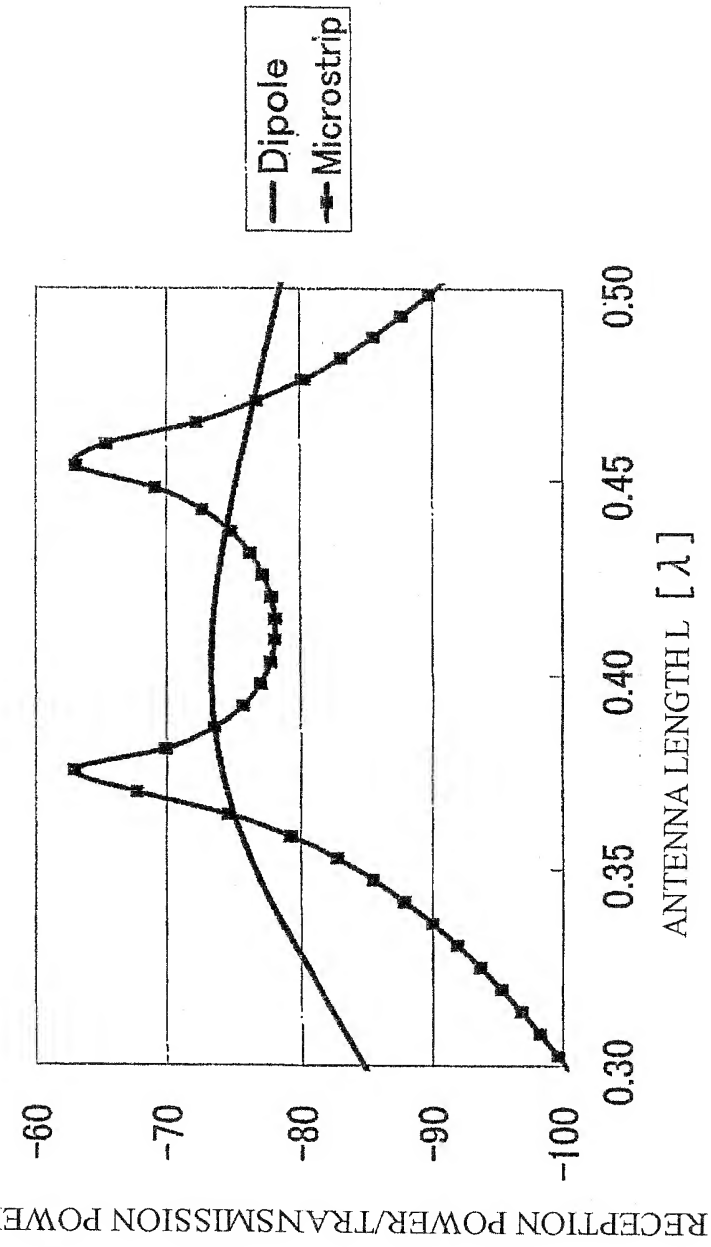

Dipole
Microstrip
-60
-70
-80
-90
-100
0.30
0.35
0.40
0.45
0.50
ANTENNA LENGTH L [λ]
RECEPTION POWER/TRANSMISSION POWER[dB]

FIG.17

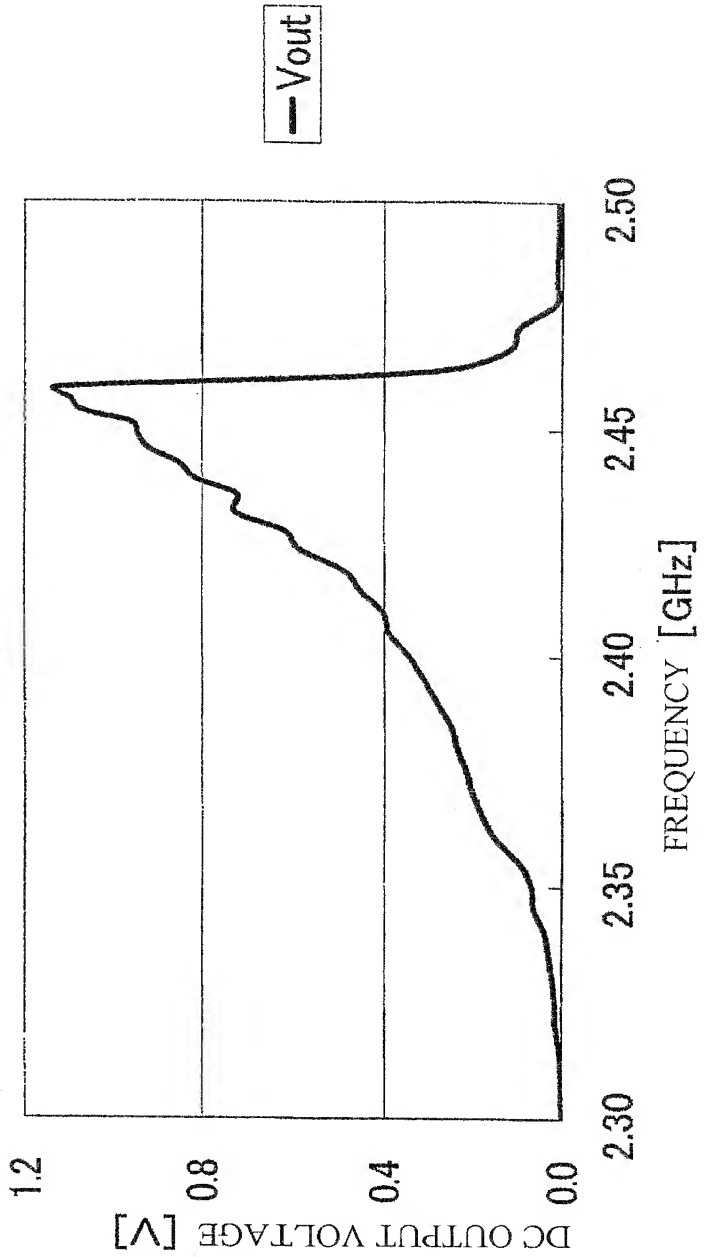

Vout
DC OUTPUT VOLTAGE [V]
1.2
0.8
0.4
0.0
2.30
2.35
2.40
2.45
2.50
FREQUENCY [GHz]

FIG.18

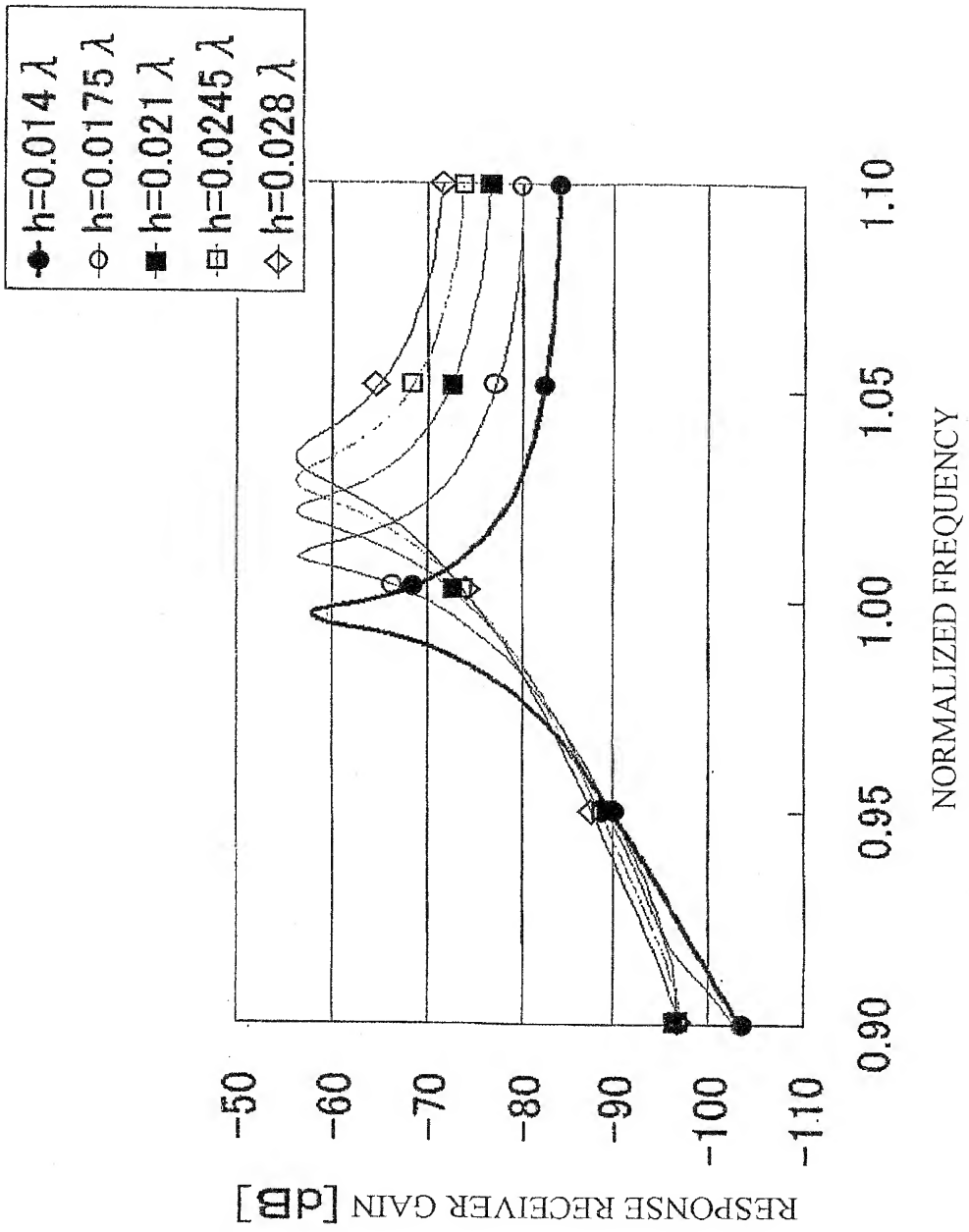

h=0.014 λ
h=0.0175 λ
h=0.021 λ
h=0.0245 λ
h=0.028 λ
RESPONSE RECEIVER GAIN [dB]
−50
−60
−70
−80
−90
−100
−110
0.90
0.95
1.00
1.05
1.10
NORMALIZED FREQUENCY

FIG.19

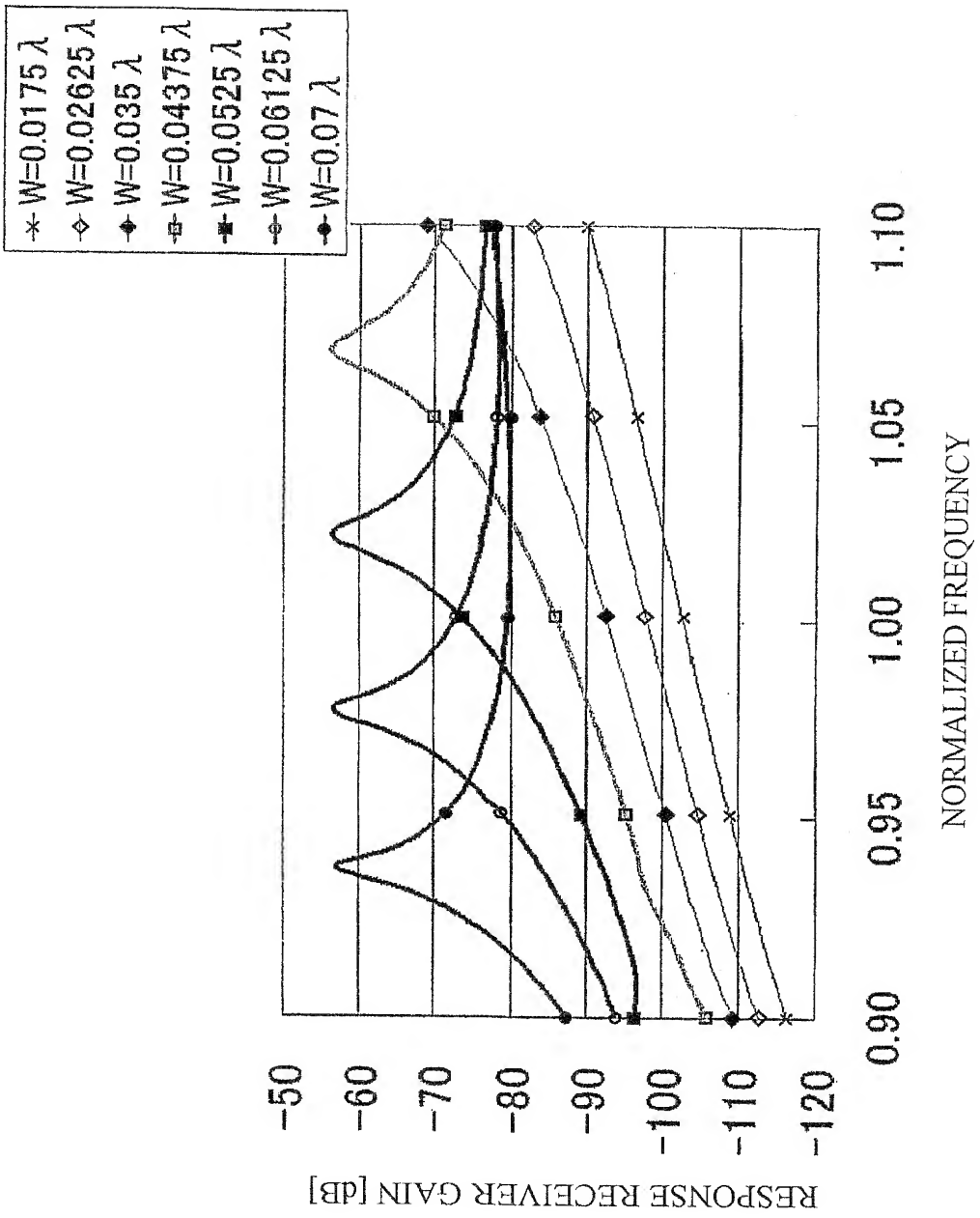

W=0.0175 λ
W=0.02625 λ
W=0.035 λ
W=0.04375 λ
W=0.0525 λ
W=0.06125 λ
W=0.07 λ
RESPONSE RECEIVER GAIN [dB]
-50
-60
-70
-80
-90
-100
-110
-120
0.90
0.95
1.00
1.05
1.10
NORMALIZED FREQUENCY

FIG.20

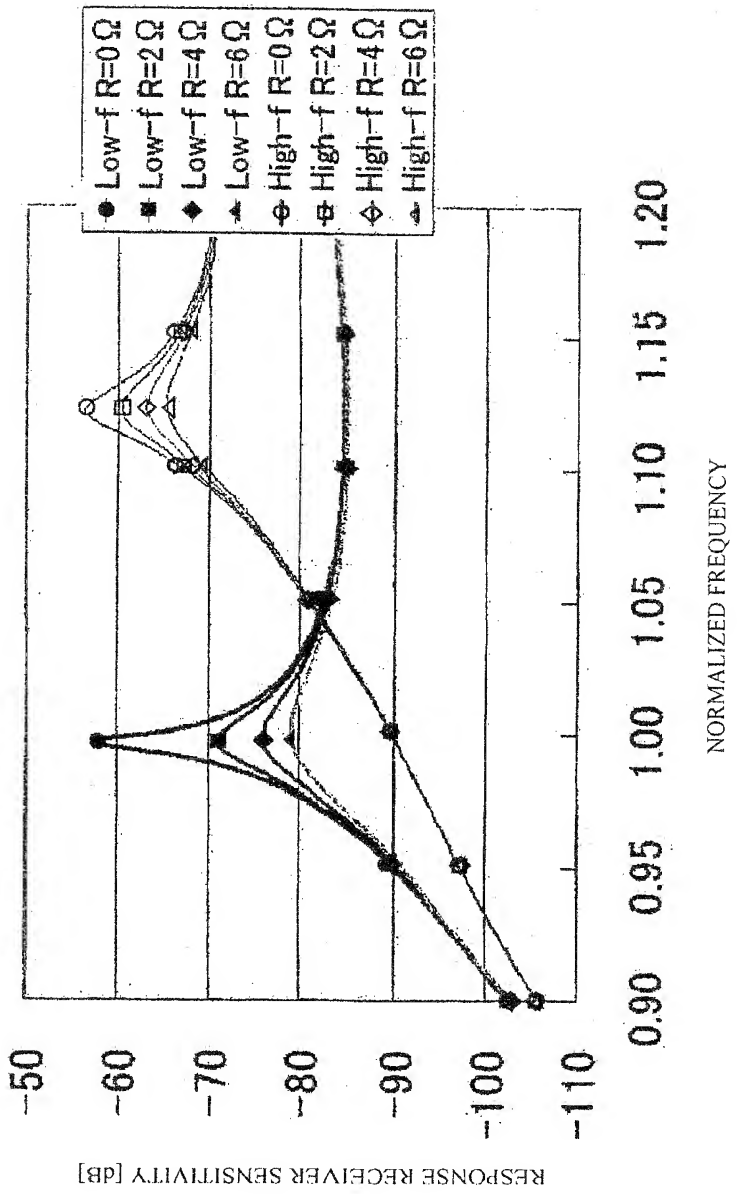

Low-f R=0Ω
Low-f R=2Ω
Low-f R=4Ω
Low-f R=6Ω
High-f R=0Ω
High-f R=2Ω
High-f R=4Ω
High-f R=6Ω
-50
-60
-70
-80
-90
-100
-110
0.90
0.95
1.00
1.05
1.10
1.15
1.20
NORMALIZED FREQUENCY
RESPONSE RECEIVER SENSITIVITY [dB]

FIG.21

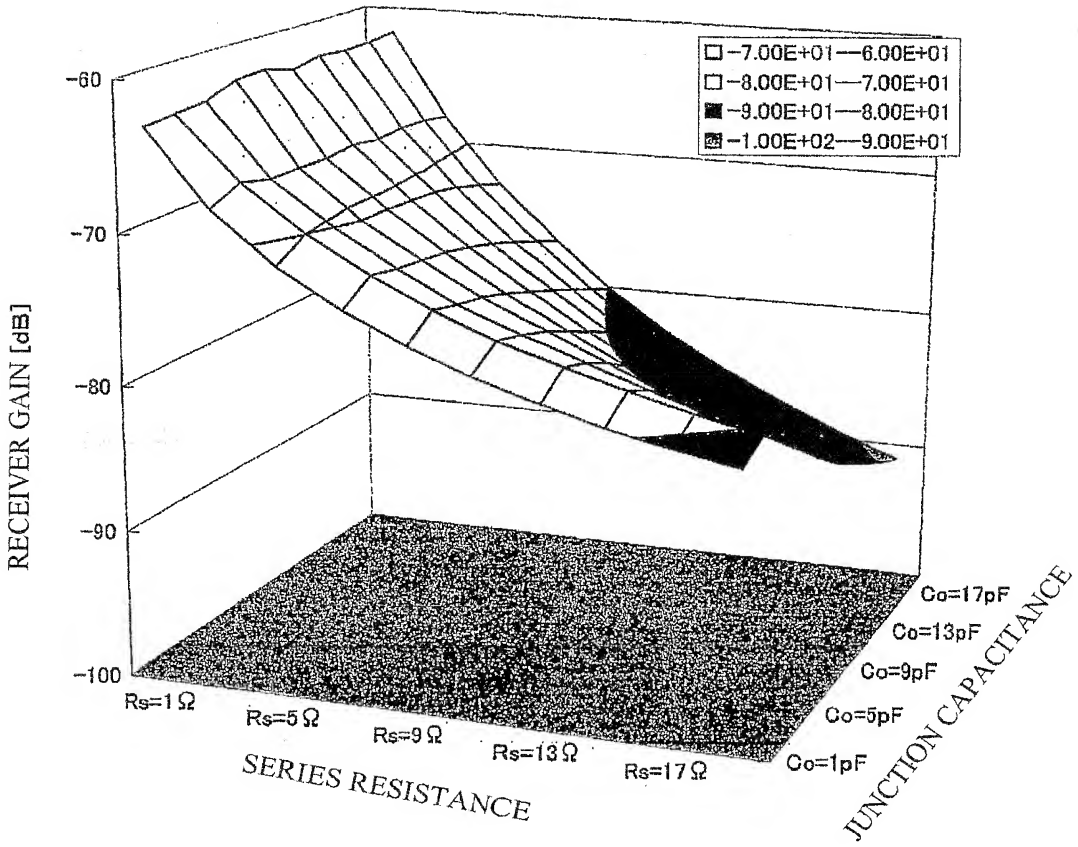

−7.00E+01—6.00E+01
−8.00E+01—7.00E+01
−9.00E+01—8.00E+01
−1.00E+02—9.00E+01
RECEIVER GAIN [dB]
−60
−70
−80
−90
−100
Rs=1Ω
Rs=5Ω
Rs=9Ω
Rs=13Ω
Rs=17Ω
SERIES RESISTANCE
Co=17pF
Co=13pF
Co=9pF
Co=5pF
Co=1pF
JUNCTION CAPACITANCE

FIG.22

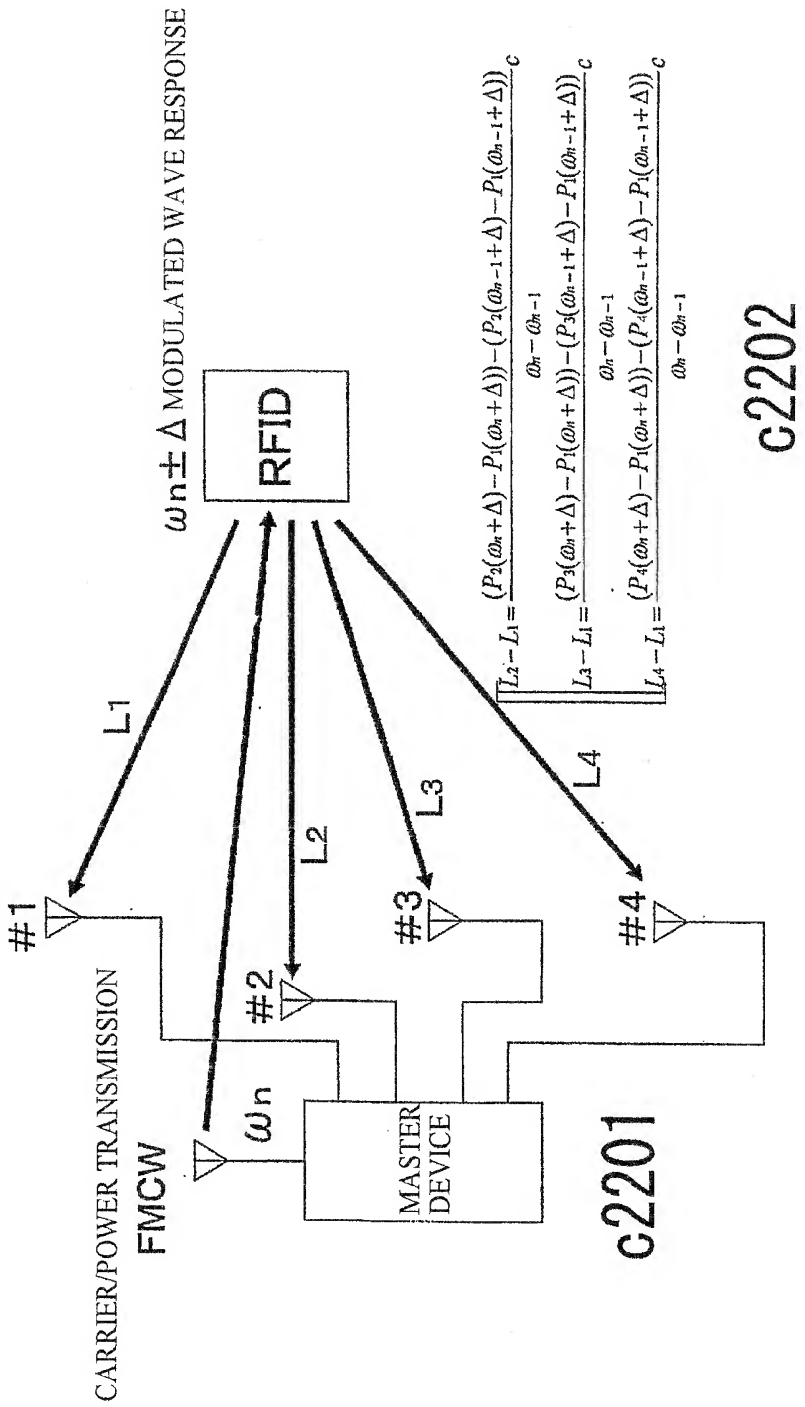

ωn±Δ MODULATED WAVE RESPONSE
RFID
L1
L2
L3
L4
#1
#2
#3
#4
CARRIER/POWER TRANSMISSION
FMCW
ωn
MASTER DEVICE
c2201
c2202
$L_2-L_1=\frac{(P_2(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_2(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$
$L_3-L_1=\frac{(P_3(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_3(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$
$L_4-L_1=\frac{(P_4(\omega_n+\Delta)-P_1(\omega_n+\Delta))-(P_4(\omega_{n-1}+\Delta)-P_1(\omega_{n-1}+\Delta))}{\omega_n-\omega_{n-1}}c$

FIG.23

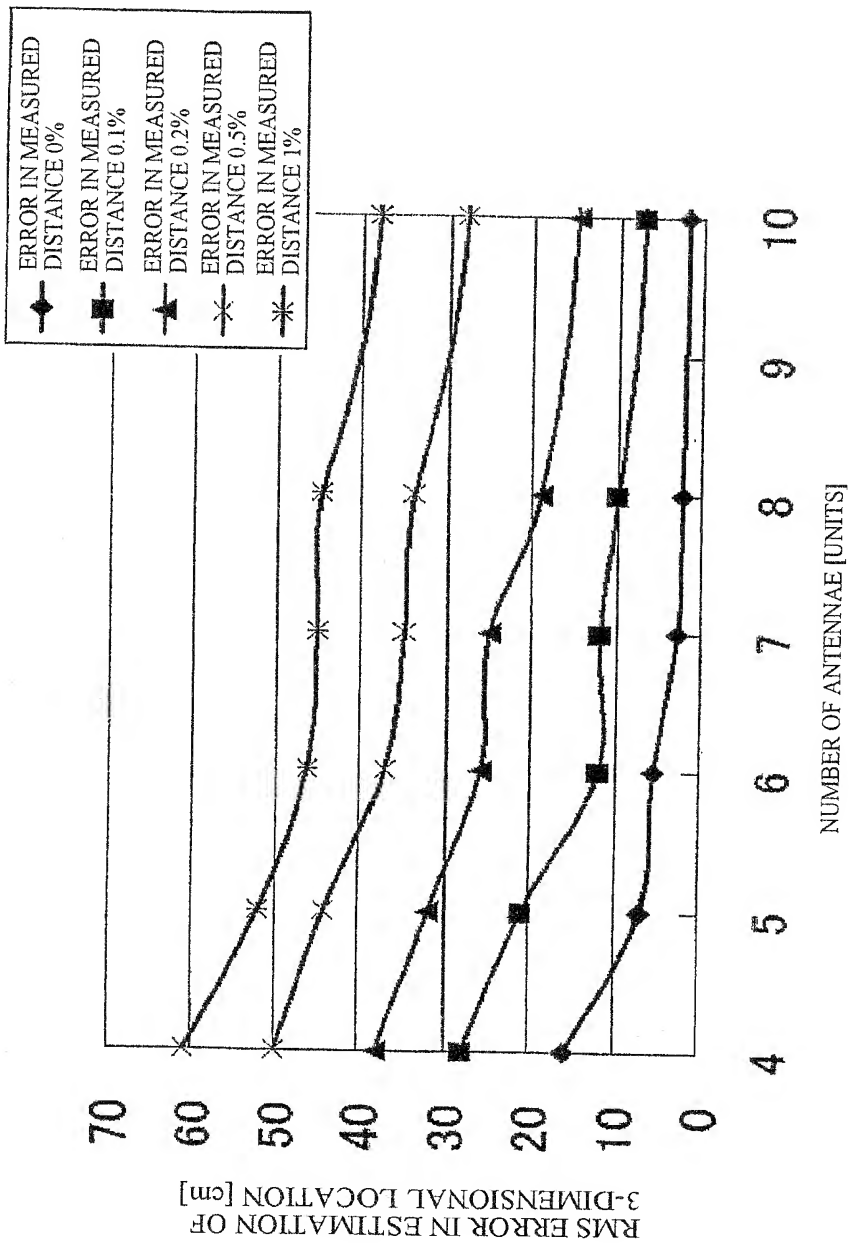

ERROR IN MEASURED DISTANCE 0%
ERROR IN MEASURED DISTANCE 0.1%
ERROR IN MEASURED DISTANCE 0.2%
ERROR IN MEASURED DISTANCE 0.5%
ERROR IN MEASURED DISTANCE 1%
RMS ERROR IN ESTIMATION OF 3-DIMENSIONAL LOCATION [cm]
70
60
50
40
30
20
10
0
4
5
6
7
8
9
10
NUMBER OF ANTENNAE [UNITS]

FIG.24

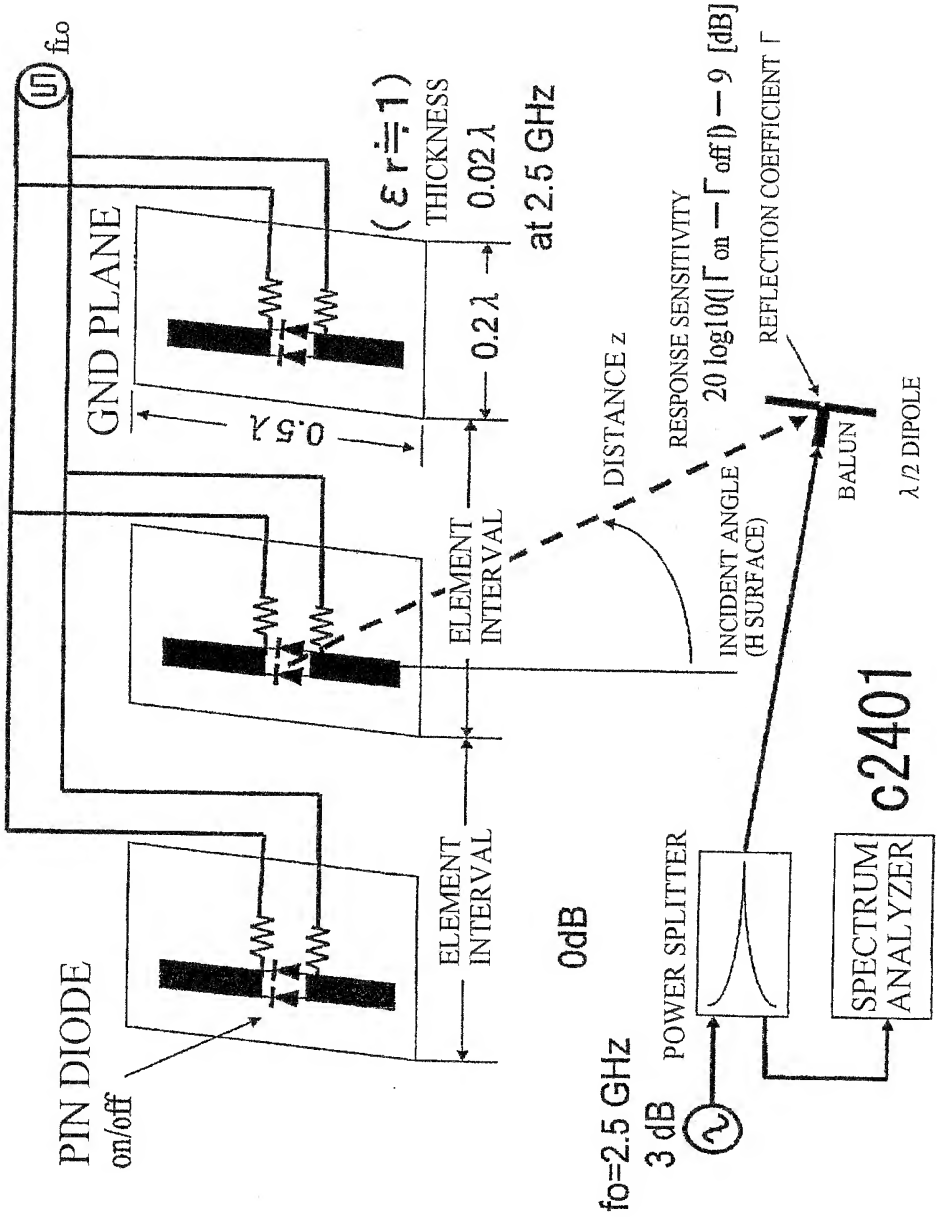

fLo
GND PLANE
0.5λ
(εr≒1)
THICKNESS
0.02λ
0.2λ
at 2.5 GHz
ELEMENT INTERVAL
ELEMENT INTERVAL
PIN DIODE
on/off
DISTANCE z
RESPONSE SENSITIVITY
20 log10(|Γ on − Γ off|) − 9 [dB]
INCIDENT ANGLE
(H SURFACE)
REFLECTION COEFFICIENT Γ
BALUN
λ/2 DIPOLE
0dB
fo=2.5 GHz
3 dB
POWER SPLITTER
SPECTRUM ANALYZER
c2401

FIG.25

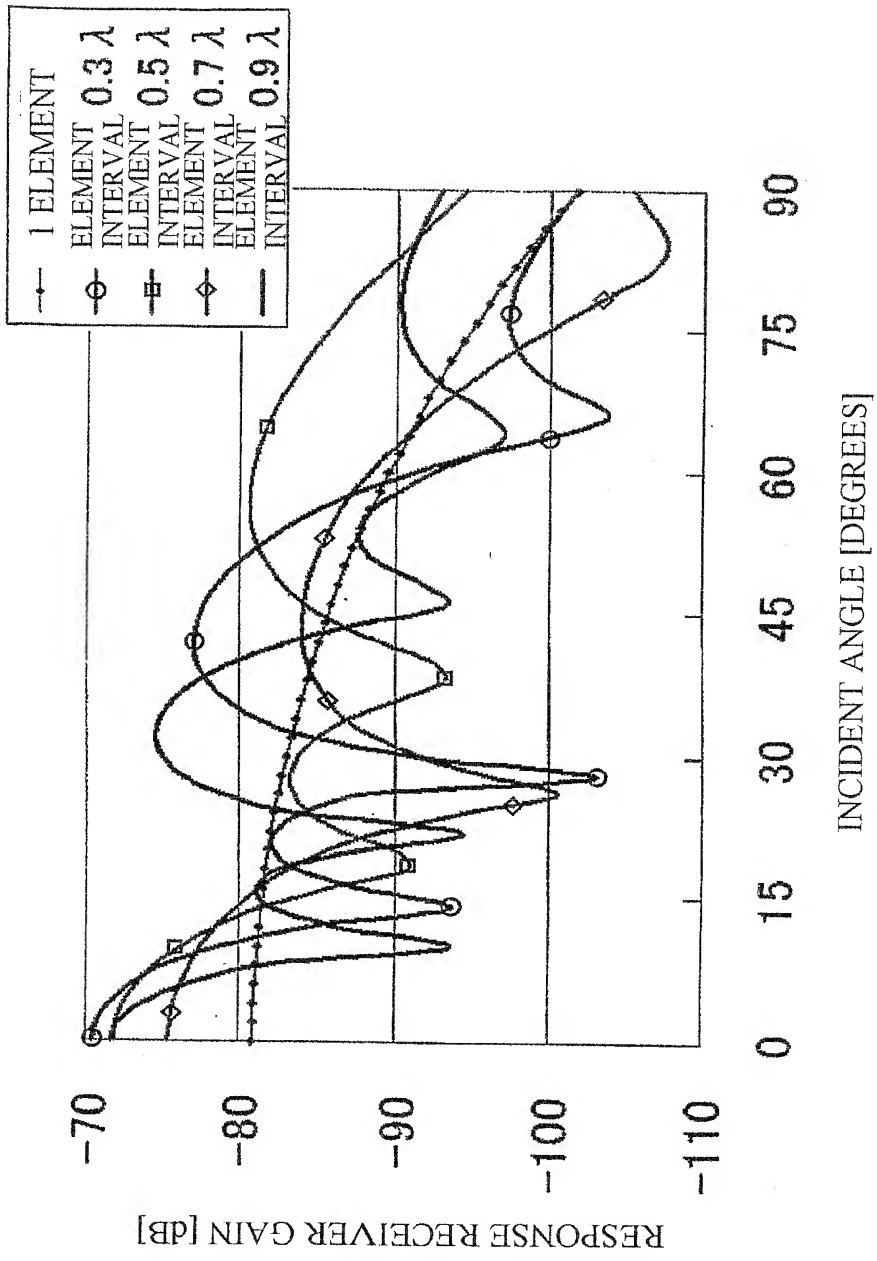

1 ELEMENT
ELEMENT INTERVAL 0.3λ
ELEMENT INTERVAL 0.5λ
ELEMENT INTERVAL 0.7λ
ELEMENT INTERVAL 0.9λ
RESPONSE RECEIVER GAIN [dB]
−70
−80
−90
−100
−110
0
15
30
45
60
75
90
INCIDENT ANGLE [DEGREES]

FIG.26

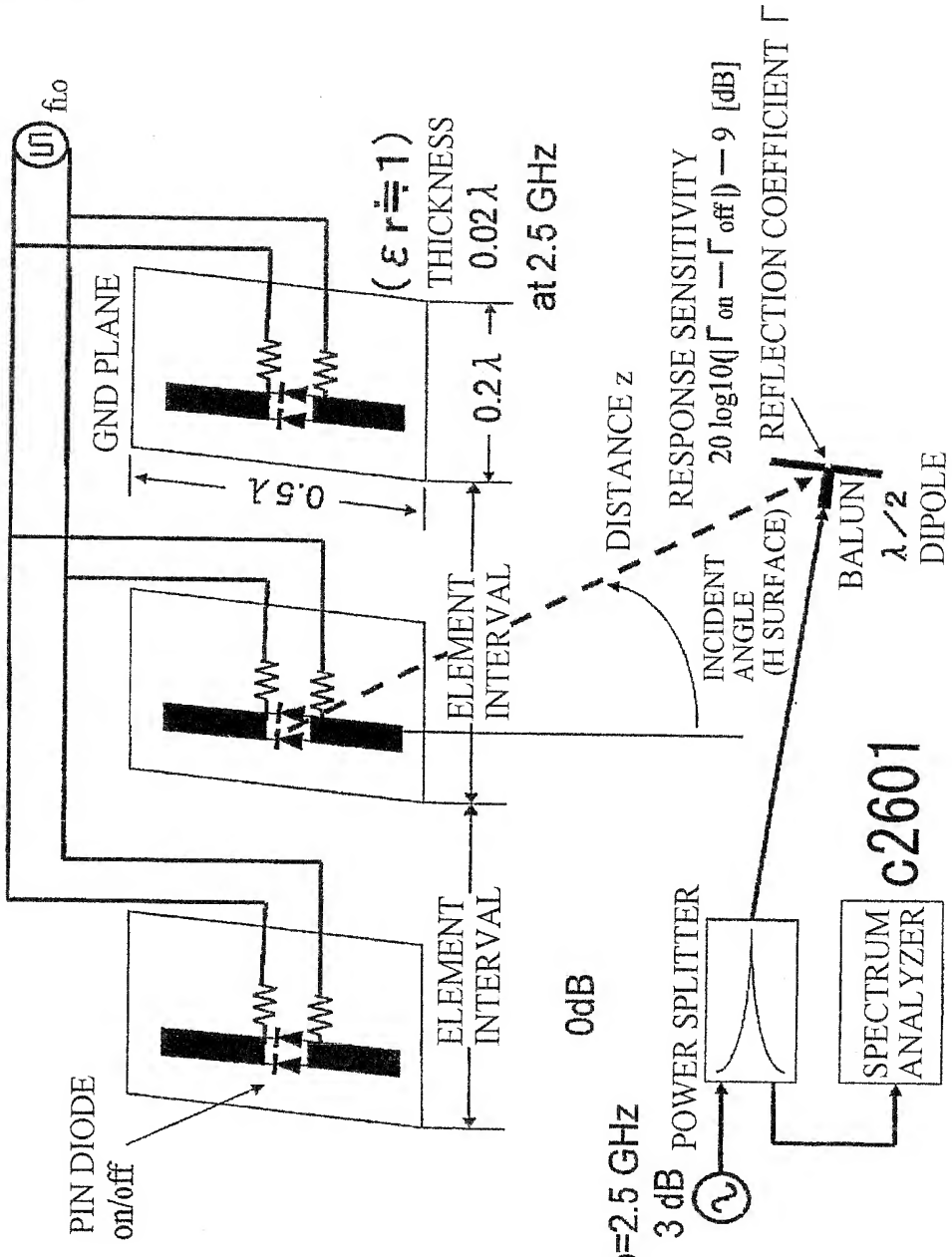

fi,o
GND PLANE
0.5λ
(εr≒1)
THICKNESS
0.02λ
0.2λ
at 2.5 GHz
ELEMENT INTERVAL
ELEMENT INTERVAL
PIN DIODE
on/off
0dB
DISTANCE z
RESPONSE SENSITIVITY
20 log10(|Γ on − Γ off|) − 9 [dB]
INCIDENT ANGLE (H SURFACE)
REFLECTION COEFFICIENT Γ
BALUN
λ/2 DIPOLE
fo=2.5 GHz
3 dB
POWER SPLITTER
SPECTRUM ANALYZER
c2601

FIG.27

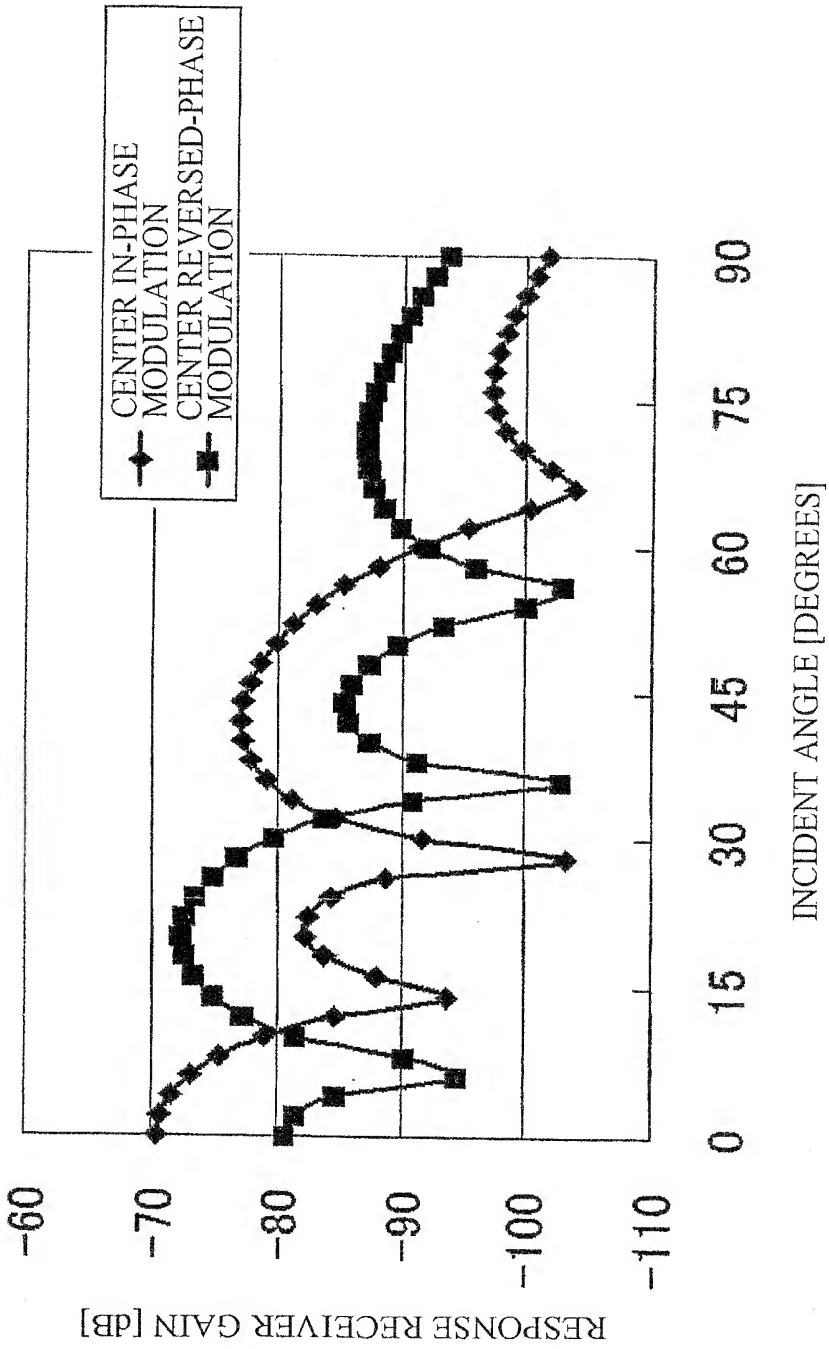

CENTER IN-PHASE MODULATION
CENTER REVERSED-PHASE MODULATION
RESPONSE RECEIVER GAIN [dB]
-60
-70
-80
-90
-100
-110
0
15
30
45
60
75
90
INCIDENT ANGLE [DEGREES]

FIG.28

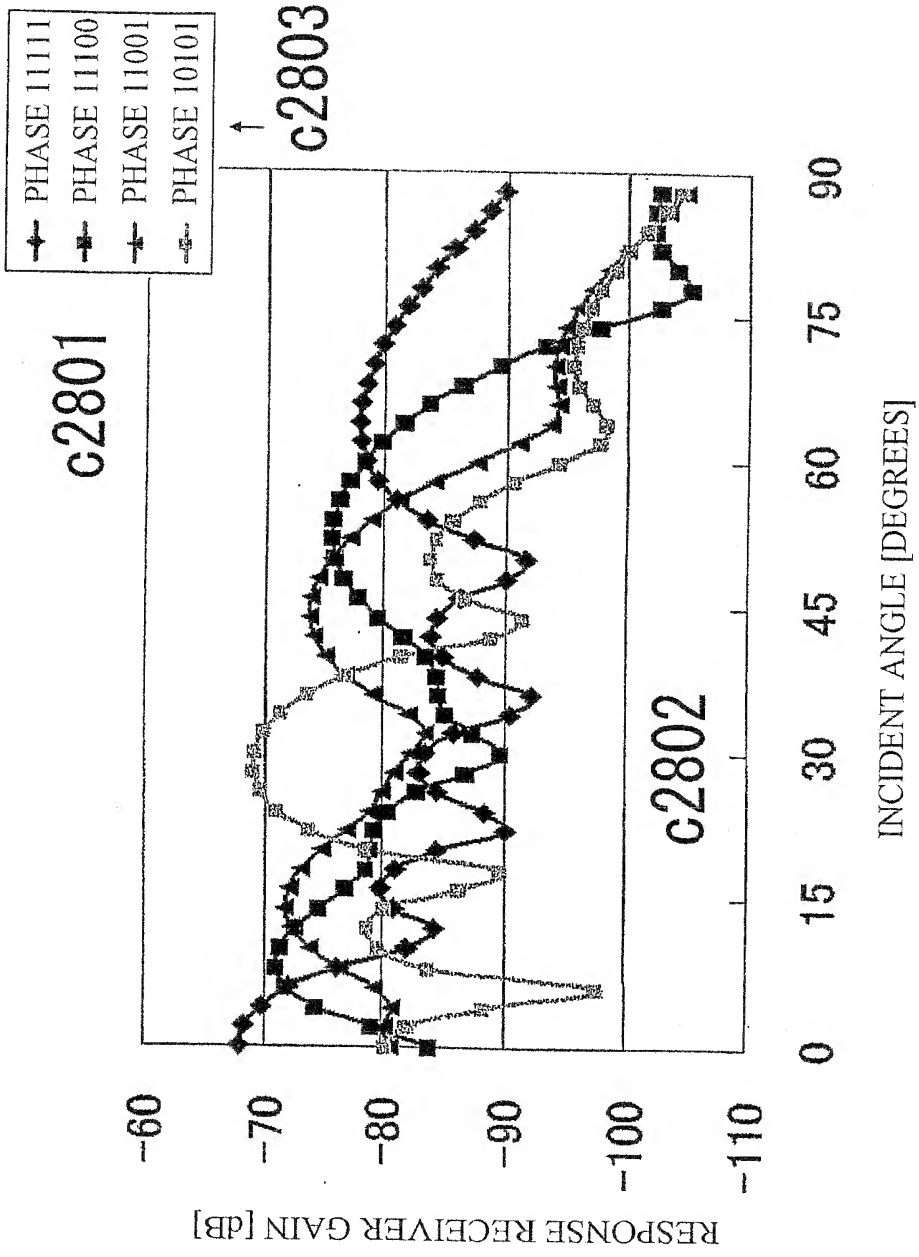

PHASE 11111
PHASE 11100
PHASE 11001
PHASE 10101
c2801
c2803
c2802
-60
-70
-80
-90
-100
-110
0
15
30
45
60
75
90
RESPONSE RECEIVER GAIN [dB]
INCIDENT ANGLE [DEGREES]

FIG.29

```
real*4 ep(5),x(5),y(5),z(5),xs(5),ys(5),zs(5)
real*4 al(200),bl(200),cl(201)

iij=1234556
f0=0.05
dlh=15.0/f0        ! cm ]  (1)
na=16
write(*,10)
format(' Enter the location of x,y,z (cm) : '$)   (2)
read(*,*,end=90) xp,yp,zp

call marray(xp,yp,zp,na,cl)   (3)
do i=2,na+1
    verr=ran(iij)
    al(i-1)=cl(i)*(1.0+(verr-0.5)*0.001)-cl(1)   ! noise 0.1 % ]  (4)
end do
write(*,*)    ⊿L(cm)',(al(i),i=1,na)
write(*,*)

call mcycle(na,dlh,al)   (5)

do i=1,5
    ep(i)=1.0e20
end do

do ix=-30,30                                    ]
    xp=float(ix)*10.0                           ]
    do iy=-30,30                                ]  (6)
        yp=float(iy)*10.0                       ]
        do iz=-30,30                            ]
            zp=float(iz)*10.0                   ]

            call marray(xp,yp,zp,na,cl)   (7)
            do i=2,na+1
                bl(i-1)=cl(i)-cl(1)-al(i-1)   (8)
            end do

            call mcycle(na,dlh,bl)   (9)
            er=0.0
            do i=1,na
                er=er+bl(i)**2    (10)
            end do
            do i=1,5                                    ]
                if (er .lt. ep(i)) then                 ]
                    if (i .ne. 5) then                  ]
                        do j=5,i+1,-1                   ]
                            ep(j)=ep(j-1)               ]
                            x(j)=x(j-1)                 ]
                            y(j)=y(j-1)                 ]
                            z(j)=z(j-1)                 ]  (11)
                        end do                          ]
                    end if                              ]
                    ep(i)=er                            ]
                    x(i)=xp                             ]
                    y(i)=yp                             ]
                    z(i)=zp                             ]
                go to 30                                ]
```

FIG.30

```
                end if
            end do
            continue
        end do
    end do
end do

do i=1,5
    xs(i)=x(i)
    ys(i)=y(i)
    zs(i)=z(i)
end do

write(*,*) ' RMS error (cm)        x              y              z    (12)
do i=1,5
    write(*,*) sqrt(ep(i)/float(na)),x(i),y(i),z(i)
end do

do m=1,5                                                              (13)
    x0=xs(m)
    y0=ys(m)
    z0=zs(m)
do ix=-15,15
    xp=float(ix)+x0
    do iy=-15,15
        yp=float(iy)+y0
        do iz=-15,15
            zp=float(iz)+z0

            call marray(xp,yp,zp,na,cl)
            do i=2,na+1
                bl(i-1)=cl(i)-cl(1)-al(i-1)
            end do

            call mcycle(na,dih,bl)
            er=0.0
            do i=1,na
                er=er+bl(i)**2
            end do

            do i=1,5
                if (er .lt. ep(i)) then
                    if (i .ne. 5) then
                        do j=5,i+1,-1
                            ep(j)=ep(j-1)
                            x(j)=x(j-1)
                            y(j)=y(j-1)
                            z(j)=z(j-1)
                        end do
                    end if
                        ep(i)=er
                        x(i)=xp
                        y(i)=yp
                        z(i)=zp
                    go to 35
                end if
            end do
```

FIG.31

```
            continue
        end do
    end do
end do

end do
write(*,*)
write(*,*) sqrt(ep(1)/float(na)),x(1),y(1),z(1)   (14)

write(*,*)
go to 20

stop
end

subroutine marray(xp,yp,zp,na,cl)

real*4 cl(1)

cl(1)=sqrt(xp*xp+yp*yp+(zp+50.0)**2)
do i=2,na+1
    ixx=i/3
    iyy=i-ixx*3
    xm=float(ixx-1)*50.0-10.0
    ym=float(iyy-1)*50.0+10.0
    cl(i)=sqrt((xp-xm)**2+(yp-ym)**2+zp*zp)
end do

return
end

subroutine mcycle(na,dlh,al)

real*4 al(1)

do i=1,na
    continue
    if (al(i) .gt. dlh) then
        al(i)=al(i)-dlh
        if (al(i) .le. dlh) go to 46
        go to 40
    end if
    continue
    if (al(i) .lt. -dlh) then
        al(i)=al(i)+dlh
        if (al(i) .ge. -dlh) go to 46
        go to 45
    end if
    continue
end do

return
end
```

FIG.32

Enter the location of x, y, z (cm) : 152, -203, 56

⊿L (cm)				
67.67562	-38.21133	-1.487458	39.09471	
-69.24731	-27.88023	16.30007	-91.74537	-46.11990
0.9732714	-102.0754	-54.30361	-5.570741	-98.28325
-51.46763	-3.269386			

RMS error (cm)	x	y	z
0.6834297	150.0000	-200.0000	60.00000
0.8562734	150.0000	-190.0000	50.00000
1.116775	150.0000	-200.0000	50.00000
1.163736	160.0000	-230.0000	70.00000
1.216863	160.0000	-220.0000	60.00000
8.4395386E-02	152.0000	-203.0000	56.00000

Enter the location of x, y, z (cm) : 22, 123, -89

⊿L (cm)				
5.506481	57.46710	16.50204	-17.27929	
55.74849	14.06553	-20.41722	66.89948	28.19106
-2.332703	89.04320	55.22502	29.83902	119.4193
90.37129	69.39222			

RMS error (cm)	x	y	z
1.445567	20.00000	130.0000	-90.00000
1.754374	20.00000	130.0000	-100.0000
1.951296	20.00000	120.0000	-80.00000
2.345274	20.00000	120.0000	-90.00000
2.709345	20.00000	140.0000	-100.0000
6.2024966E-02	22.00000	123.0000	-89.00000

Enter the location of x, y, z (cm) : 60, 161, 5

⊿L (cm)				
-23.45399	32.54938	-13.85323	-57.41031	
21.66080	-27.96993	-77.36571	22.85288	-26.38201
-74.96463	36.05470	-9.367880	-51.50449	59.00156
18.86572	-15.62937			

RMS error (cm)	x	y	z
1.358104	60.00000	160.0000	10.00000
1.400364	60.00000	160.0000	0.0000000E+00
1.561480	60.00000	170.0000	0.0000000E+00
1.779230	60.00000	170.0000	10.00000
1.850774	60.00000	150.0000	10.00000
4.4650473E-02	60.00000	161.0000	5.000000

Enter the location of x, y, z (cm)